Optical Diagnostic Suite (Schlieren, Interferometry, and Angular Filter Refractometry) on OMEGA EP Using a 10-ps, 263-nm Probe Beam

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Project Overview:

A 4ω probe laser and optical diagnostic suite is available on OMEGA EP

- A 10-ps, 20-mJ, 4ω probe laser is implemented on OMEGA EP
- The system will initially be configured for
  - schlieren/shadowgraphy
  - angular filter refractometry (AFR)
  - interferometry
- The design presents options for expanded optical diagnostics
- Advanced optical-design tools are being adapted to provide synthetic diagnostic images for experimental setup and analysis

The three diagnostics coupled with detailed optical modeling will provide a novel diagnostic platform.

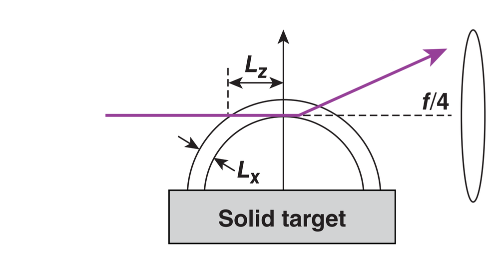
*R. S. Craxton et al., Phys. Fluids B 5, 4419 (1993).

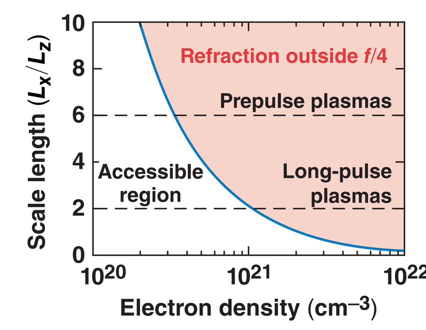
Collection System

The optical collection system will provide access to high-density laser-produced plasmas

An f/4 system:

- long-pulse plasmas ($L_x/L_z \sim 2$): $n_e = 10^{21}$ cm^{-3}
- prepulse plasmas ($L_x/L_z \sim 6$): $n_e = 10^{20}$ cm^{-3}

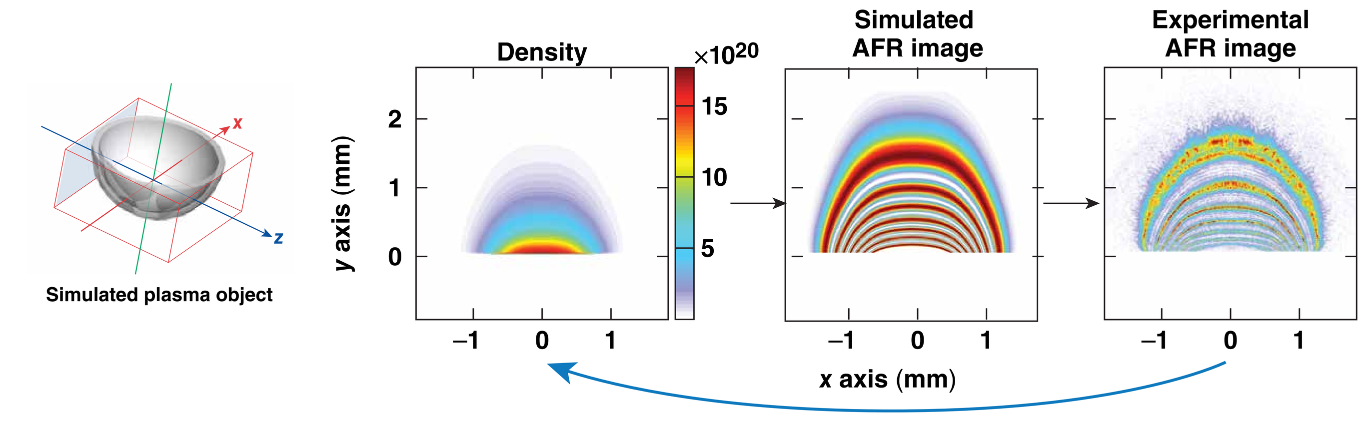




An f/4 system will provide access to highly refractive plasmas.

Optical Modeling

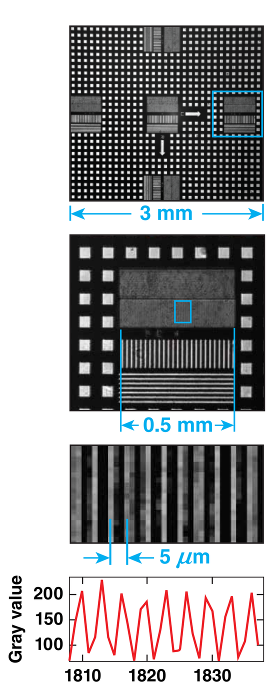
A complete analysis package is being developed to provide experimental design and complex data reduction



This infrastructure will be available for experimental planning, data analysis, and advanced diagnostic design.

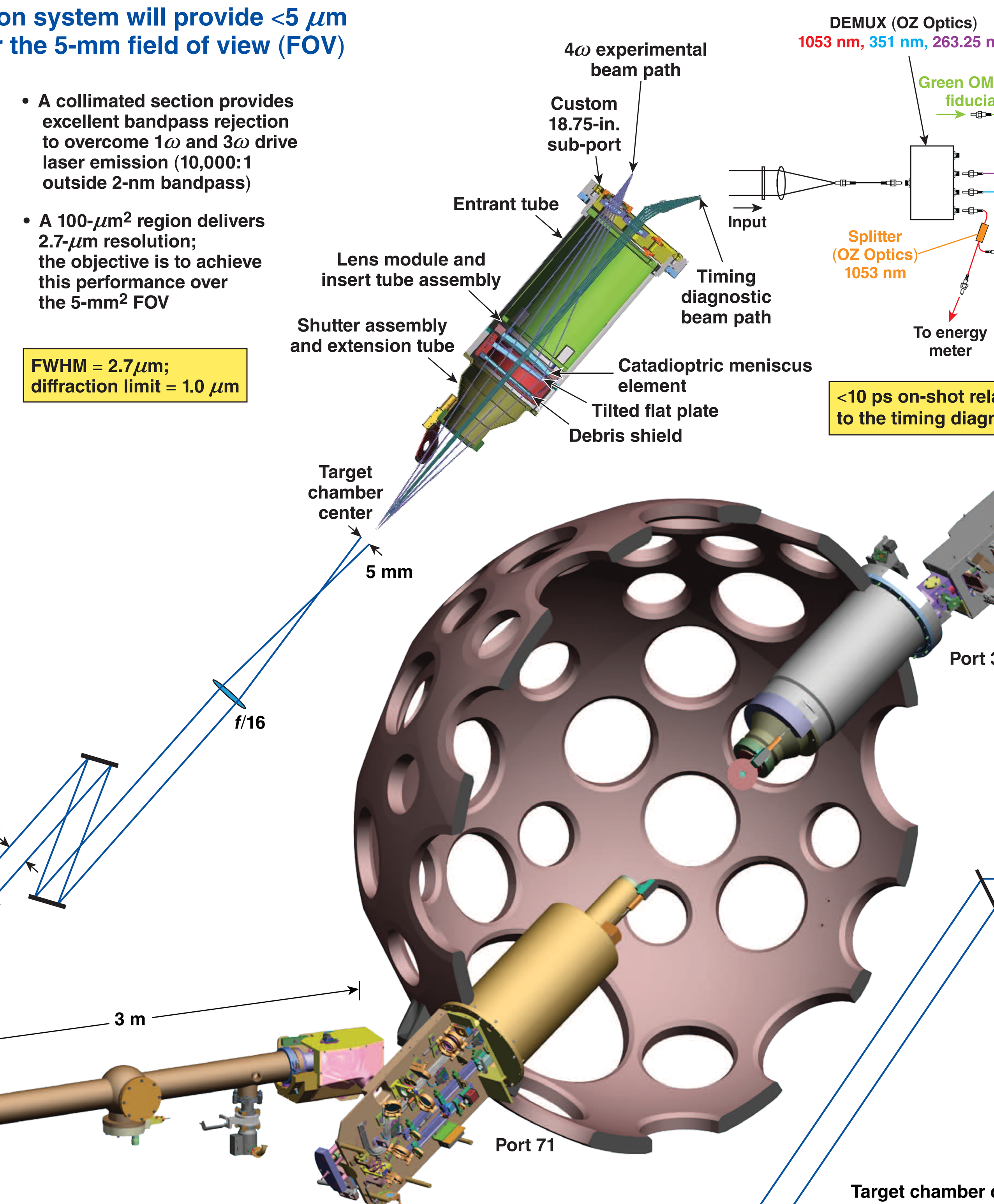
Catadioptric Collection System

The f/4 collection system will provide <5 μm resolution over the 5-mm field of view (FOV)

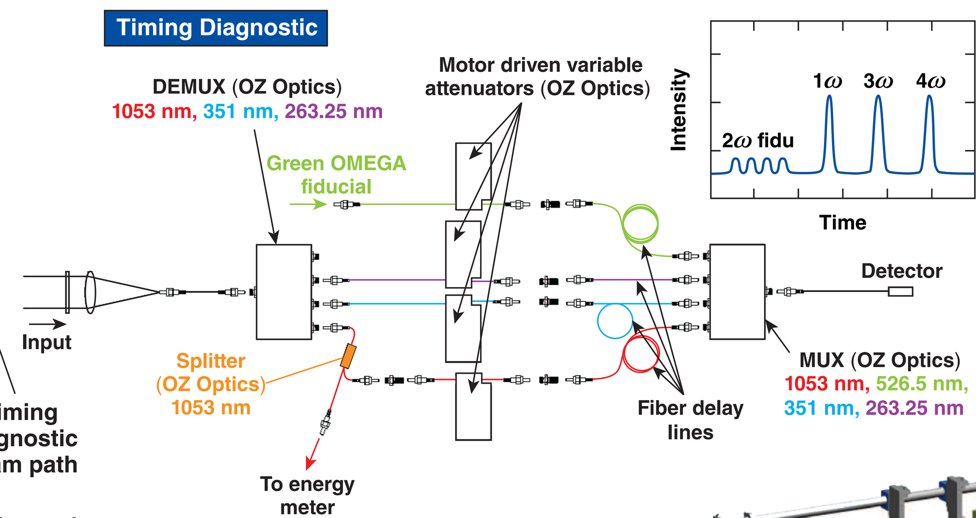


- A collimated section provides excellent bandpass rejection to overcome 1ω and 3ω drive laser emission (10,000:1 outside 2-nm bandpass)
- A 100-μm^2 region delivers 2.7-μm resolution; the objective is to achieve this performance over the 5-mm^2 FOV

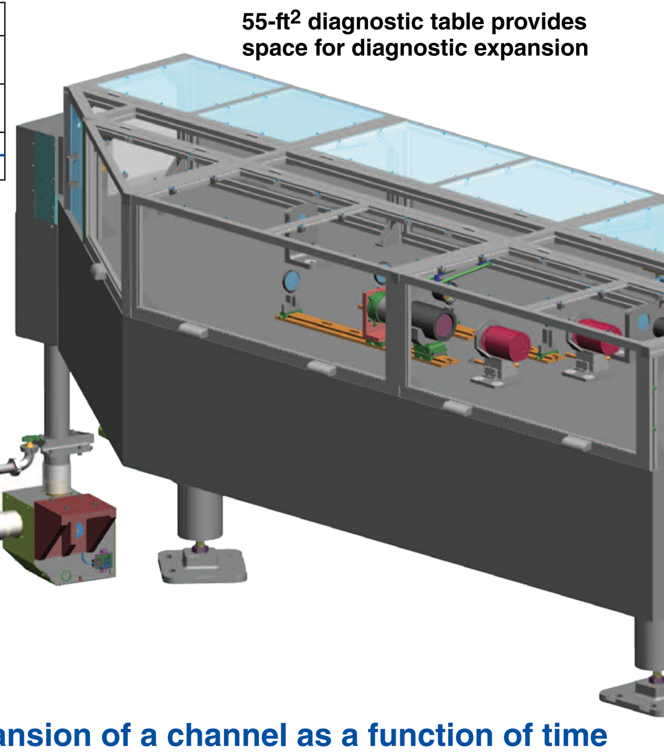
FWHM = 2.7 μm; diffraction limit = 1.0 μm



Timing Diagnostic



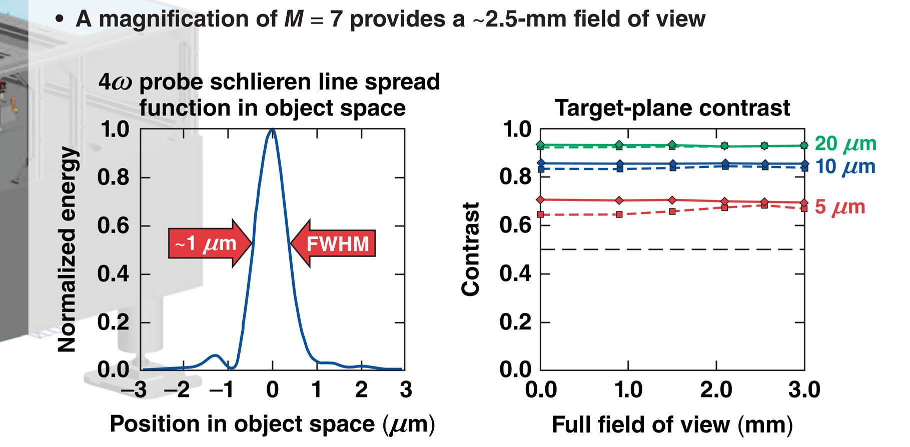
<10 ps on-shot relative to the timing diagnostic



Schlieren/shadowgraphy

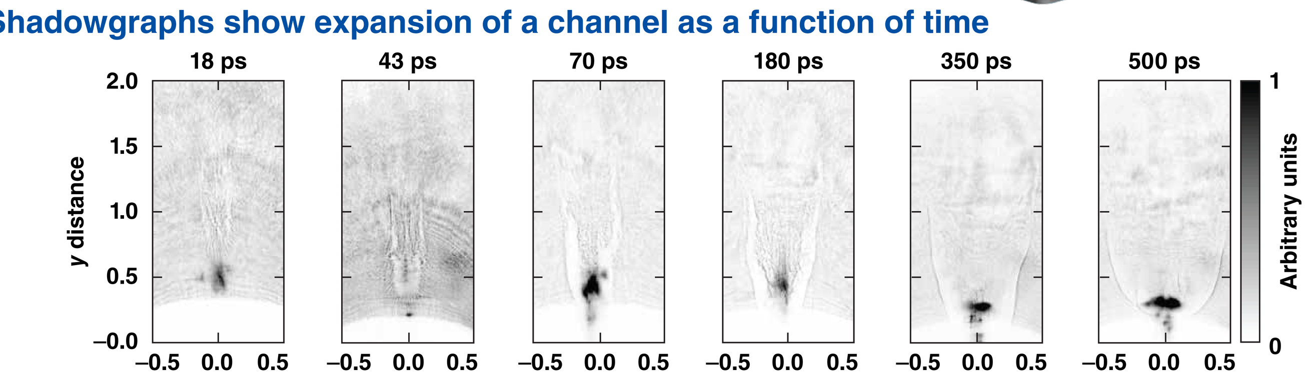
Modeling indicates the schlieren optical design can produce 1-μm resolution in the plasma plane

- Convolved with the charge-coupled–device (CCD) pixels and realistic optical performance, a <10-μm resolution is anticipated
- A magnification of $M = 7$ provides a ~2.5-mm field of view

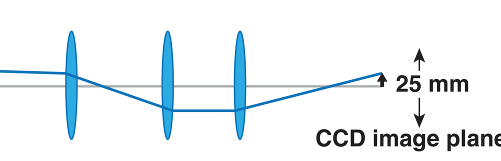


Shadowgraphy

Shadowgraphs show expansion of a channel as a function of time



Shadowgraph images for the 100-ps channeling pulse at various probing times. The channel boundary radially expands forming a shock wave into the unperturbed plasma material. Time zero is defined at the start (50 ps from the center) of the 100-ps pulse. The bright edge highlights the channel wall and occurs as a result of a local refractive index variation over the width of the shockwave caused by the density jump.

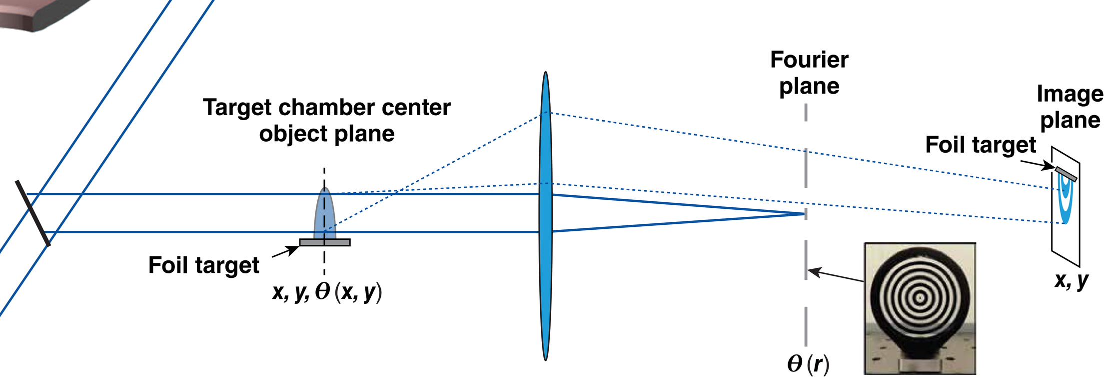


The system is designed to produce high resolution over the 3.6-mm field of view.

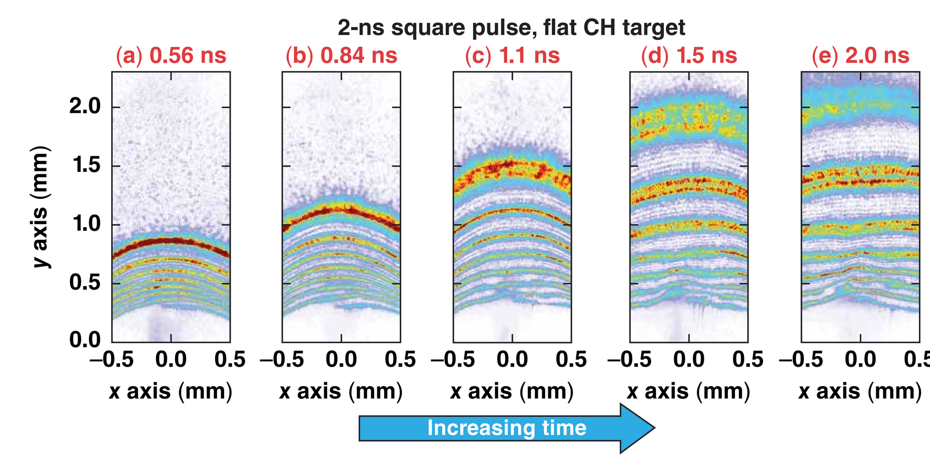
Angular Filter Refractometry

Angular filter refractometry maps the refraction of the probe beam at target chamber center to contours in the image plane

- Processing the experimental angular refactometry images creates a contour map of the refraction angle
- The system is designed to have <50-μm resolution over a 3.6-mm field of view
- Magnification of 7×

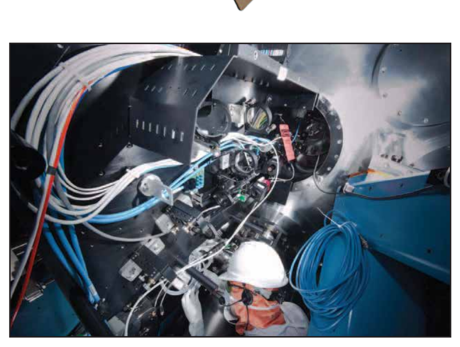


The temporal evolution of the plasma density profile of UV-irradiated planar targets is illustrated using the angular filter refractometer



Central portions of AFR images illustrating plasma expansion from flat CH targets irradiated with 9 kJ of ultraviolet (UV, 351-nm) light in a millimeter spot; the images were obtained at probe timings of (a) 0.56 ns, (b) 0.84 ns, (c) 1.1 ns, (d) 1.5 ns, and (e) 2.0 ns

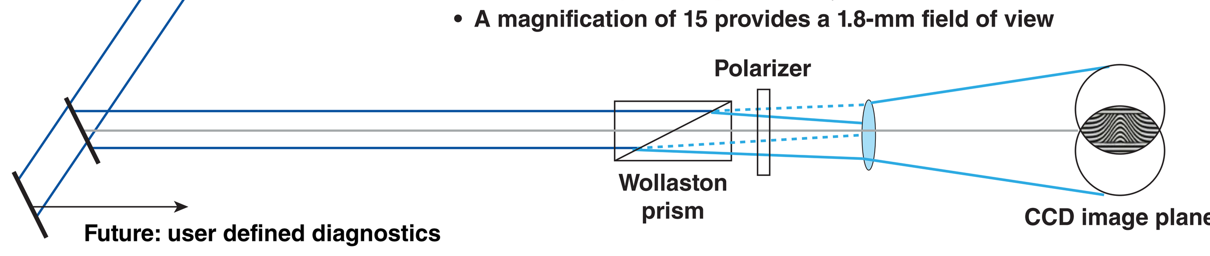
AFR provides the density measurements to 10^{21} cm^{-3} in long-scale-length plasmas.



Interferometer

Interferometry is limited to electron densities below ~4×10^{20} cm^{-3} in laser-produced plasmas

- Interferometry is designed for 5-μm resolution
- A magnification of 15 provides a 1.8-mm field of view



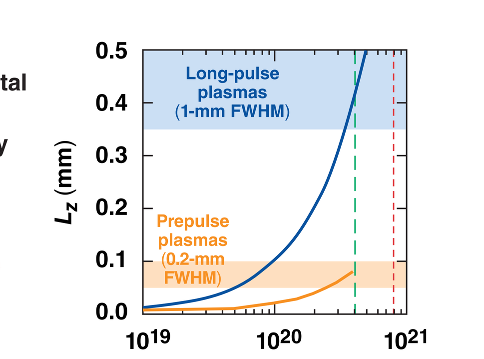
Experimental design considerations

- The probe beam must overlap plasma and vacuum
- The polarization will be rotated to align fringes with experimental configuration
- The scale lengths (L_x, L_z) limit the maximum accessible density

$$\left|\frac{\nabla\phi(x,z)}{2\pi}\right|_{max} < \frac{1\ \text{wave}}{8\ \text{pixels}}$$

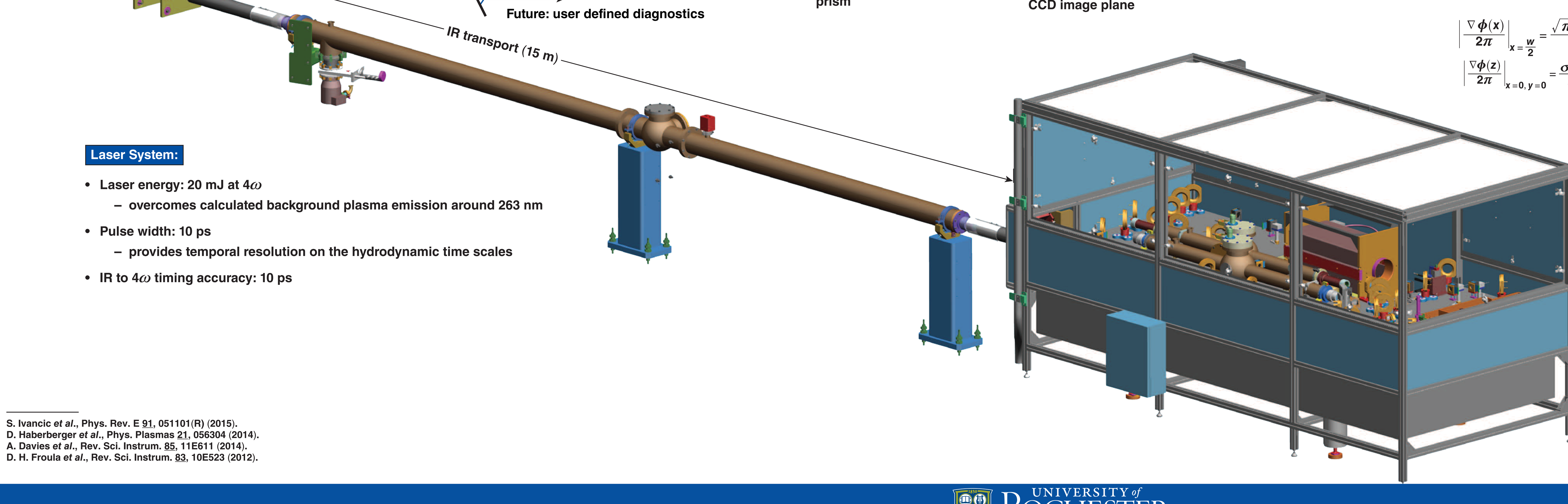
$$\left|\frac{\nabla\phi(x)}{2\pi}\right|_{x=\frac{w}{2}} = \frac{\sqrt{\pi\ln(2)}}{2\lambda}\left(\frac{n_{e,0}}{n_{cr}}\right) < \frac{1}{8\ \text{pixels}} \longrightarrow n_{e,0} < 7\times10^{20}\ \text{cm}^{-3}$$

$$\left|\frac{\nabla\phi(z)}{2\pi}\right|_{x=0,\,y=0} = \frac{\sigma\sqrt{\pi}}{2\lambda}\left(\frac{n_{e,0}}{n_{cr}}\right)\left(\frac{1}{L_z}\right) < \frac{1}{8\ \text{pixels}} \longrightarrow n_{e,0} < 4\times10^{20}\ \text{cm}^{-3}$$

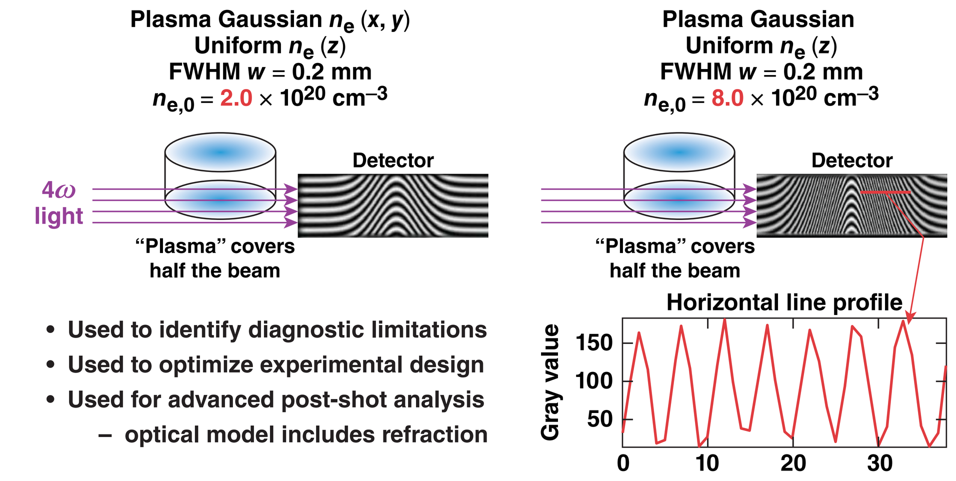


Laser System:

- Laser energy: 20 mJ at 4ω
  - overcomes calculated background plasma emission around 263 nm
- Pulse width: 10 ps
  - provides temporal resolution on the hydrodynamic time scales
- IR to 4ω timing accuracy: 10 ps



Optical modeling can be used to optimize experimental design and identify limitations



- Used to identify diagnostic limitations
- Used to optimize experimental design
- Used for advanced post-shot analysis
  - optical model includes refraction

Danger zone: close to the sampling limit!

S. Ivancic et al., Phys. Rev. E 91, 051101(R) (2015).
D. Haberberger et al., Phys. Plasmas 21, 056304 (2014).
A. Davies et al., Rev. Sci. Instrum. 85, 11E611 (2014).
D. H. Froula et al., Rev. Sci. Instrum. 83, 10E523 (2012).